Demonstrating the Effect of Particle Impact Dampers on the Random Vibration Response and Fatigue Life of Printed Wiring Assemblies

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In a recent experimental study, small Particle Impact Dampers (PID) were bonded directly to the surface of printed circuit board (PCB) or printed wiring assemblies (PWA), reducing the random vibration response and increasing the fatigue life. This study provides data verifying practicality of this approach. The measured peak strain and acceleration response of the fundamental out of plane bending mode was significantly attenuated by adding a PID device. Attenuation of this mode is most relevant to the fatigue life of a PWA because the local relative displacements between the board and the supported components, which ultimately cause fatigue failures of the electrical leads of the board-mounted components are dominated by this mode. Applying PID damping at the board-level of assembly provides mitigation with a very small mass impact, especially as compared to isolation at an avionics box or shelf level of assembly. When compared with other mitigation techniques at the PWA level (board thickness, stiffeners, constrained layer damping), a compact PID device has the additional advantage of not needing to be an integral part of the design. A PID can simply be bonded to heritage or commercial off the shelf (COTS) hardware to facilitate its use in environments beyond which it was originally qualified. Finite element analysis and test results show that the beneficial effect is not localized and that the attenuation is not due to the simple addition of mass. No significant, detrimental reduction in frequency was observed. Side-by-side life testing of damped and un-damped boards at two different thicknesses (0.070" and 0.090") has shown that the addition of a PID was much more significant to the fatigue life than increasing the thickness. High speed video, accelerometer, and strain measurements have been collected to correlate with analytical results.

Nomenclature

ESSSA = Engineering and Science Services and Skills Augmentation
MSFC = Marshall Space Flight Center

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I. Introduction

Random vibration tests are commonly specified for qualification and acceptance of printed wiring assemblies (PWA's) because they accurately capture the qualities of the real service environments in a wide range of industries and applications. As the bending modes of the board respond to these inputs, localized stresses and strains develop at the component interfaces to the board and on the components themselves. These stresses, which may ultimately result in fatigue failures, are a direct result of relative displacements between the board and the attached components. An example illustrating the influence of the fundamental board mode on relative displacement is given in Figure 1. It can be seen that although the higher order modes contribute to the RMS acceleration as the PSD is integrated, a $1/\omega^2$ factor causes the relative displacement, (and thus the stress and strain) to be determined by the fundamental mode.

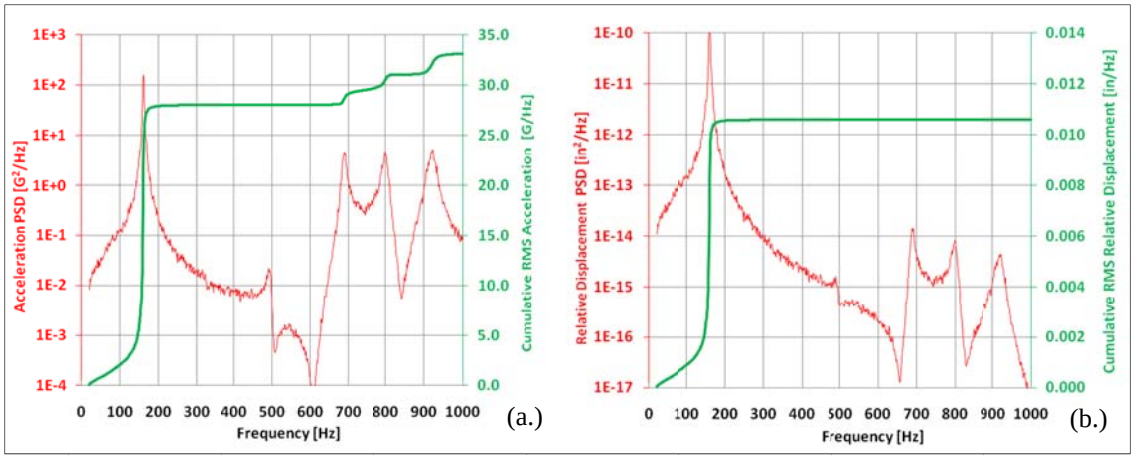

Figure 1 Finite element power spectral density response at the center of a board and cumulative root mean square response (RMS). (a.) Acceleration Response (b.) Relative displacement response

Targeting this mode with a particle damper is simple and intuitive. An effective approach has been to bond the housing as close as possible to the anti-node to maximize the energy transfer into the device.

II. Varying Particle Mass

A preliminary test sequence was designed to investigate response changes as the number of particles increased. Of particular concern was to determine if the displacement reduction from the damping increase would keep pace with any displacement increase from the anticipated frequency shift as mass was added to the PID. For this, the first test article consisted of a 0.070" thick, 4" x 7" reinforced fiberglass board populated with 4 column grid arrays. Figure 2 shows the board with an early PID housing design that allowed for progressively adding 0.080" Tungsten particles. Three test environments (Table 1) were applied at increasing fill levels, to a maximum of 94 particles. At maximum fill, the PID device represented ~7% of the total test article mass.

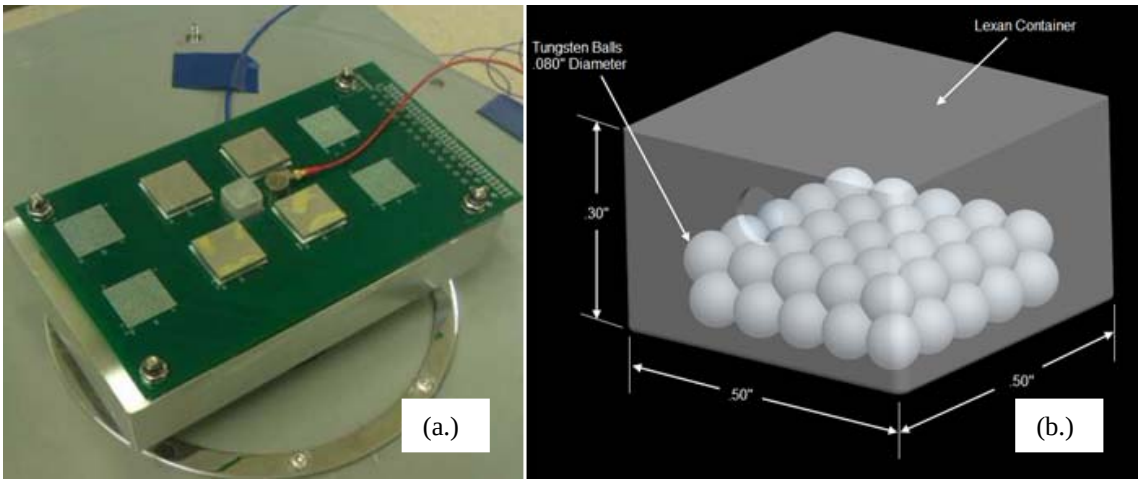

Figure 2 Test configuration with "fillable" particle damper housing. (a.) Assembly on vibration table. (b.) Container detail.

Table 1 Prototype Vibration Test Environments

+0dB		+3dB		+6dB	
Freq. [Hz]	**PSD [g^2/Hz]**	**Freq. [Hz]**	**PSD [g^2/Hz]**	**Freq. [Hz]**	**PSD [g^2/Hz]**
20	0.01	20	.02	20	.04
80	.04	80	.08	80	.16
1000	.04	1000	.08	1000	.16
Grms	**6.19**	**Grms**	**8.75**	**Grms**	**12.38**

Figure 3 compares the random vibration response before and after the addition of particles at the +6 dB test level. The peak response of the targeted mode was attenuated by more than 10 dB with none of the anticipated detrimental frequency shift. The lack of frequency shift was a beneficial phenomenon common to all test configurations and random excitation levels. It is in contrast with the behavior noted during swept sine vibration and predicted in modal analysis. A possible explanation is that the rather than acting as mass added to the system, the particle impacts are small, random forcing functions often acting out of phase with the motion of the board.

Figure 4 summarizes the change in root mean square acceleration with excitation and PID fill level. As a rule, the trend was that the particle damper became more effective as the number of balls was increased and at higher excitation levels.

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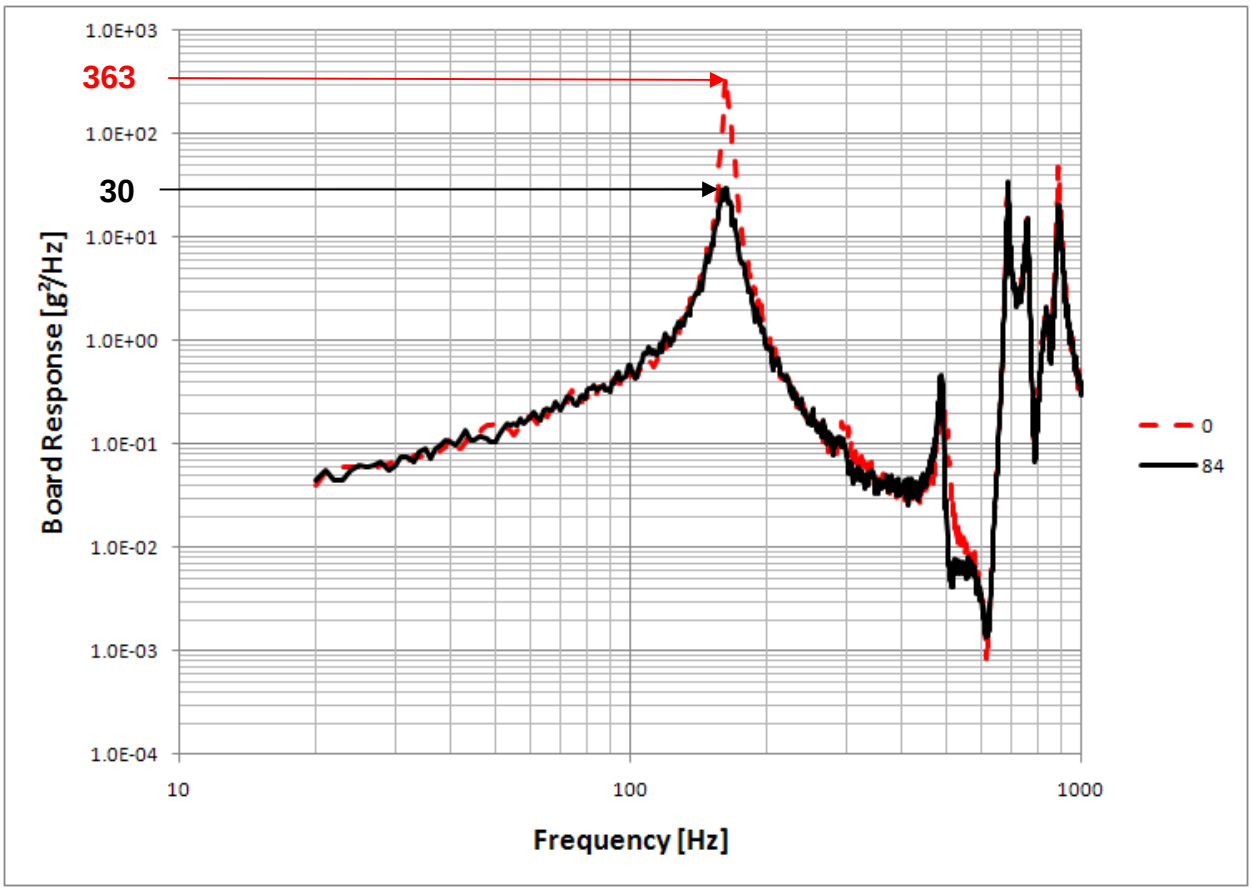

Figure 3 Acceleration spectral density at the center of a PWA at +6dB vibration Level. Comparison of response with empty housing to response with 84 Tungsten particles.

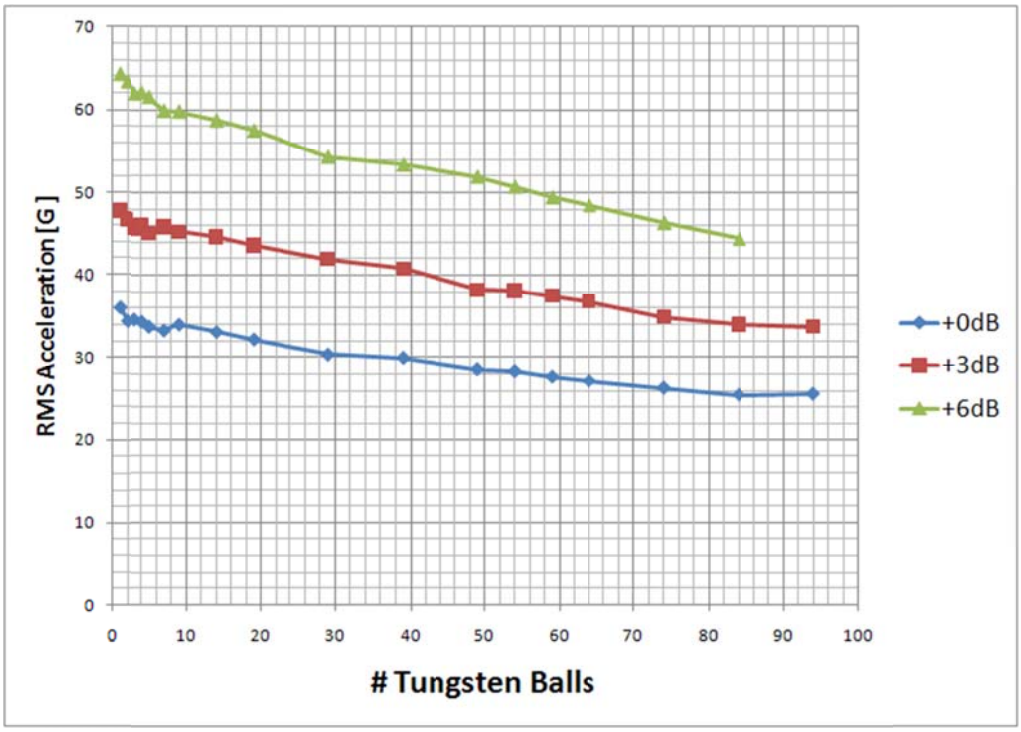

Figure 4 Effect of excitation amplitude and PID fill level on board center RMS acceleration.

III. Life Testing

A second series of tests was conducted to verify that the previously observed vibration attenuation actually translates into meaningful increases in fatigue life. Secondary objectives included maturing the design of the particle damper housing and bonding process and collecting strain measurements. For this series, the overall design of the circuit cards remained the same (4" x 7" reinforced fiberglass board populated with 4 column grid arrays), but 8 assemblies were built in two thicknesses, 0.70" and 0.90".

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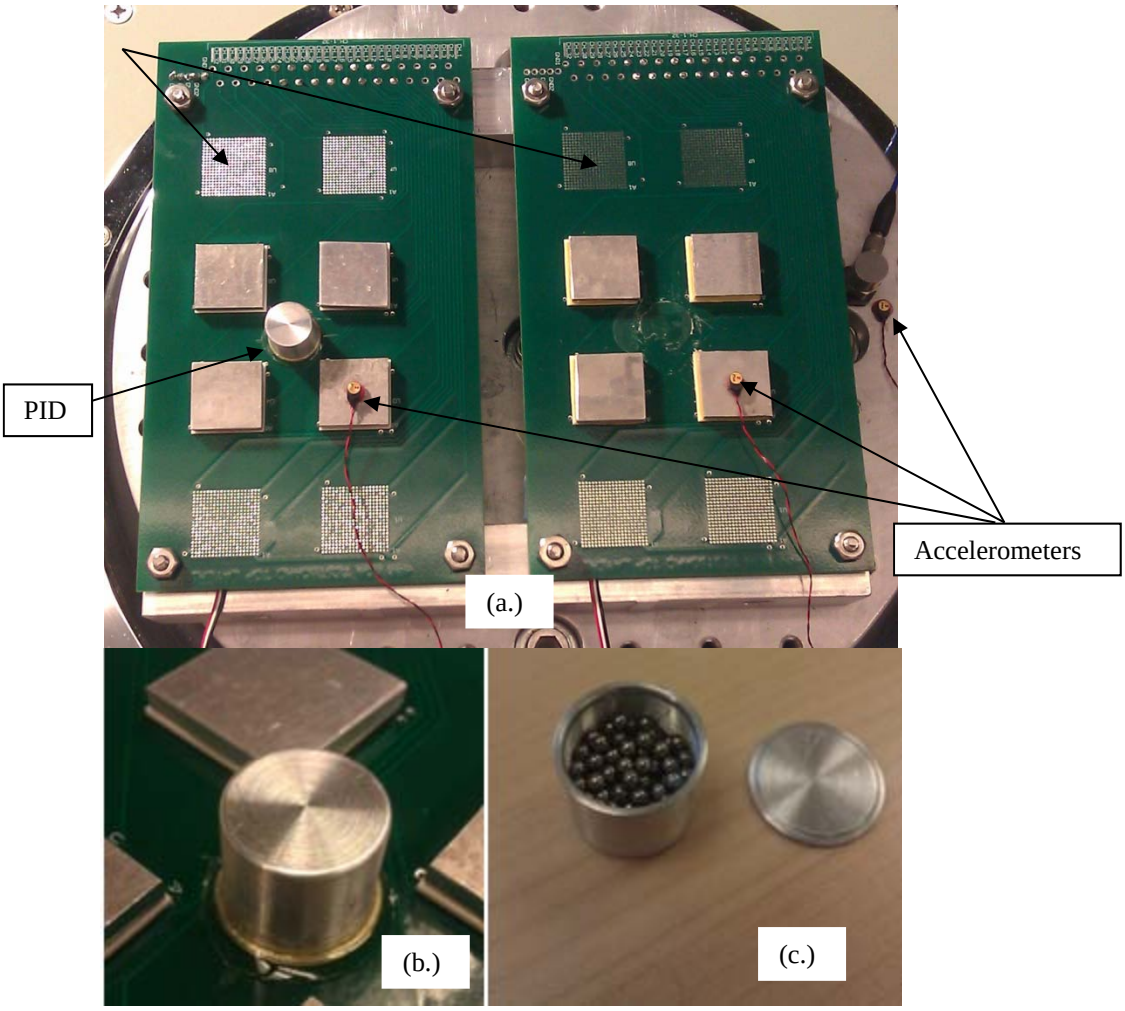

Figure 5 PWA fatigue test articles (a.) Side by side testing of damped and un-damped boards (b.) Particle damper bonded to board (c.) Open damper filled with 145 Tungsten particles. Cover, (removed here) is in contact with board when installed.

Figure 5 shows how the fatigue test articles were tested side-by-side. Test environment was a minimum workmanship screen level +6dB in all cases.

From several candidates, the new particle damper design was a thin-walled 1/2" x 9/16" cylindrical aluminum housing with 145 Tungsten particles (12.4 grams). A full fillet bond around the container using epoxy adhesive, DP190 Gray held the PID to the board. This bond was later found to be effective in separate testing with inputs up to 0.80 g^2/Hz.

Each of the column grid arrays was daisy-chained such that its 400 leads could monitored with 4 data collection channels on an Anatech resistance monitoring system. (100 leads per channel, 16 channels per board) During vibration testing, a channel failure was defined as a total increase in resistance to greater than 1000 Ohms. The time of each failure was recorded.

Figure 6 shows a Weibull analysis of the channel failures for damped and un-damped boards of two board thicknesses (two of each type). It is noteworthy, that one of the measures commonly used to increase the fatigue life of a PWA, increasing thickness, was much less effective than the addition of the PID devices.

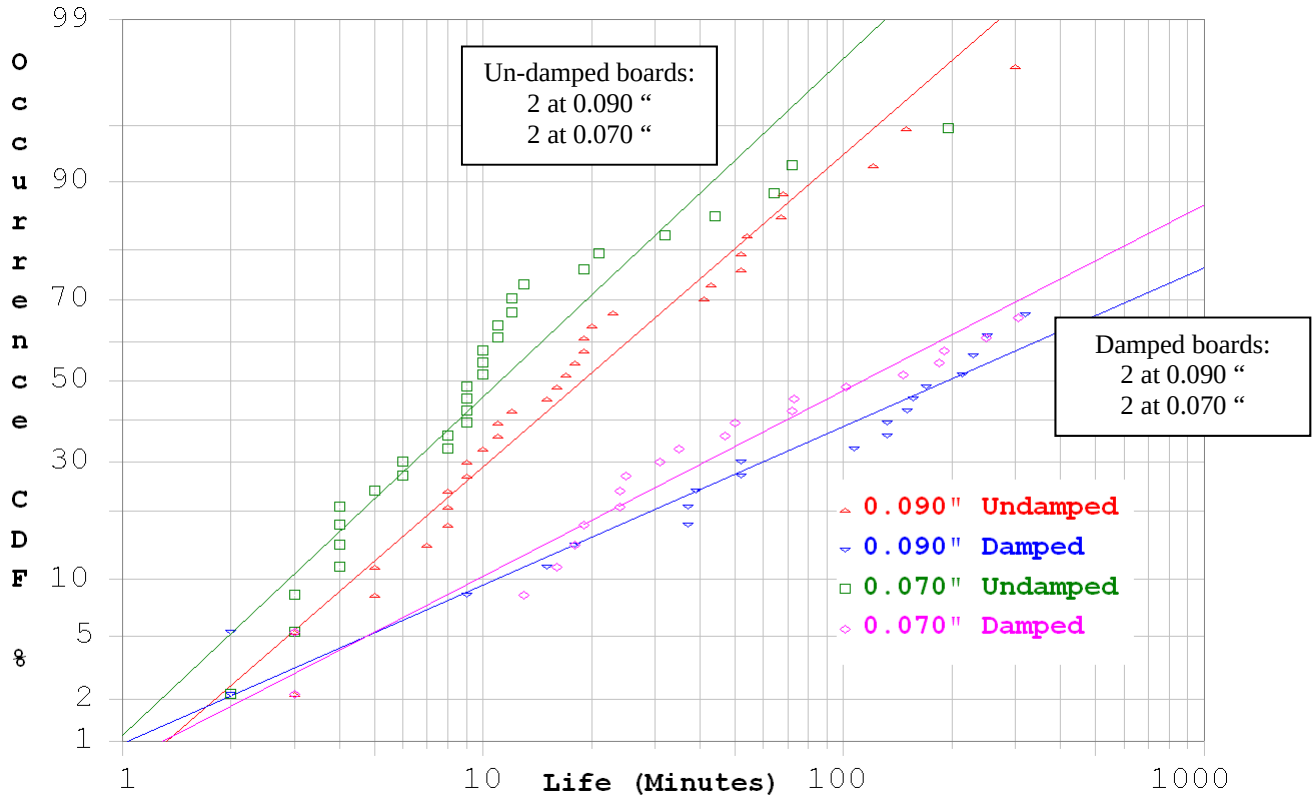

Figure 6 Weibull Analysis of channel failures

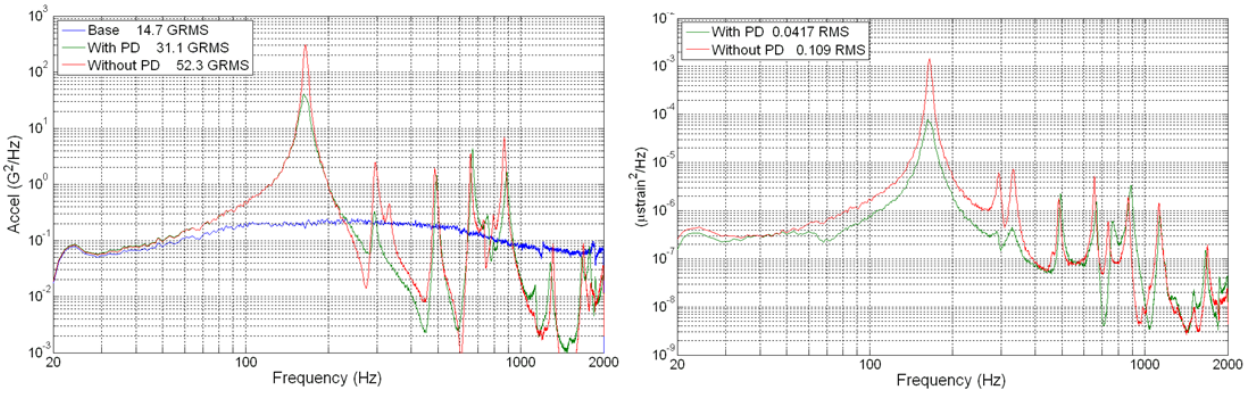

Figure 7 Acceleration and strain spectral densities measured during life testing. Comparison of undamped to damped PWA's

IV. Conclusions

The results of these engineering development test will examine the effect of particle damping on the vibration response and fatigue life of printed wiring assemblies exposed to acoustic random vibration environments. The data measured from this test series will be useful for characterizing the potential to attenuate harsh environments using particle damping devices. Additionally, the data will provide useful design information to size and locate particle damping devices to maximize attenuation.